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A TECHNOLOGY TO MEASURE MULTIPLE DRIVING BEHAVIORS WITHOUT SELF-REPORT OR PARTICIPANT REACTIVITY

THOMAS E. BOYCE

UNIVERSITY OF NEVADA, RENO

AND

E. SCOTT GELLER

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

An in-vehicle information system (IVIS) was used to videotape drivers ($N = 61$) without their knowledge while driving 22 miles in normal traffic. The drivers were told that they were participating in a study of direction following and map reading. Two data-coding procedures were used to analyze videotapes. Safety-related behaviors were counted during consecutive 15-s intervals of a driving trial, and the occurrence of certain safety-related behaviors was assessed under critical conditions. These two methods of data coding were assessed for practicality, reliability, and sensitivity. Interobserver agreement for the five different driving behaviors ranged from 85% to 95%. Within-subject variability in safe driving was more pronounced among younger drivers and decreased as a function of age. Contrary to previous research that has relied on self-reports, driver risk taking did not vary significantly as a function of gender. These results are used to illustrate the capabilities of the technology introduced here to design and evaluate behavior-analytic interventions to increase safe driving.

DESCRIPTORS: driving safety, observation methodology, instrumented vehicle, participant reactivity

Risky driving is common in contemporary society and leads to substantial loss. For example, in 1996 risky driving in the U.S. contributed to 41,907 fatalities and 3.5 million serious injuries from vehicle crashes (National Highway Traffic Safety Administration [NHTSA], 1998). As such, approximately 115 U.S. residents die each day in motor vehicle crashes, amounting to one death every 13 min. These tragedies occur despite environmental safeguards designed to protect vehicle occupants, and mandatory laws to decrease the occurrence of driving behaviors that increase the probability of a crash. Hence, Geller (1991) called the U.S. highways a battleground claiming more lives than any war this country has ever seen.

Minor changes in driver behavior can prevent injury and save lives. For example, the occurrence of vehicle crashes has been shown to vary directly with changes in the national speed limit (Evans, 1991). Moreover, it is estimated that safety-belt use saved 10,414

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Correspondence concerning this article should be addressed to Thomas E. Boyce, who is now at the Department of Psychology, University of Nevada–Reno, Reno, Nevada 89557 (E-mail: teboyce@unr.edu) or E. Scott Geller, Center for Applied Behavior Systems, 5100 Derring Hall, Department of Psychology, Virginia Tech, Blacksburg, Virginia 24061-0436 (E-mail: esgeller@vt.edu).

lives in 1996 and a total of 90,425 lives since 1975 (NHTSA, 1998). In fact, it is predicted that a 1% increase in the use of safety belts nationwide saves 200 lives per year (Nichols, 1998). Given this, it is alarming that nationwide belt use is below 70% (Nichols), and many drivers choose to drive in ways that put themselves and others at risk for a vehicle crash and serious injury.

Risky driving is predictive of involvement in fatal vehicle crashes. For example, Rajalin (1994) reported that licensed drivers who had been involved in a fatal crash were more likely to have been convicted of a driving offense in the 3-year period preceding the fatality than were randomly selected licensed drivers who had not been involved in a fatal crash. An analysis of demographic variables showed that the fatal-crash drivers were younger and more likely to be male than were the randomly selected drivers in the control group. Similar findings were reported by Hunter, Stewart, Stutts, and Rodgman (1993), who showed that among 5,074 residents of North Carolina, drivers observed not using their safety belts experienced 35% more vehicle crashes and 69% more driving convictions (as indicated by court records and actual accident reports) than those observed to use their safety belts.

However, these and other studies of driving behavior have been limited methodologically. That is, they have used self-reports, archival data, or human observers who can reliably observe only a few behaviors at a time (e.g., Burns & Wilde, 1995). Attempts to relate driving outcomes and individual differences have used self-reported or agency-obtained crash-frequency data as the primary variable (e.g., Arthur & Graziano, 1996; Jonah, 1990). Lajunen, Corry, Summala, and Hartley (1997) demonstrated the tendency for participants to engage in impression management and self-deception when completing traffic behavior inventories (i.e., they often gave answers reflecting socially approved behaviors rather than actual driving practices). And, actual crash data are difficult to evaluate on an individual-subject level due to the infrequency of occurrence (Elander, West, & French, 1993).

To address the issue of dependent-measure integrity, recent research has investigated the viability of in-vehicle information systems (IVIS) that aid drivers in decision making during driving (e.g., Dingus, 1995). The focus of this research has been to study the impact of collision-avoidance warning, in-vehicle signing and warning displays, and routing and navigation systems to study the effects of an IVIS on driving behaviors (Boyce & Neale, 1998). In contrast, the present research studied how the IVIS technology could be used to unobtrusively assess ongoing individual driver behavior.

The present research investigated the utility and reliability of an IVIS to assess relations among several driving behaviors and individual characteristics such as driver gender and age. An IVIS can record several driving behaviors at the same time, making it possible to study covariance among multiple driving behaviors. Some of these relations could have ramifications for the design of interventions to improve driving safety. For example, Ludwig and Geller (1991, 1997, 2000) reported generalization of intervention effects from one target behavior in a response class to others that were not targeted.

The IVIS developed and evaluated in the present research was termed a “Smart Car.” The Smart Car is an instrumented vehicle capable of video recording and measuring ongoing driving performance without a driver’s knowledge. Computer-generated dependent measures, in concert with real-time video recordings of the participant’s driving, allowed unprecedented opportunities to perform a behavioral analysis of driving performance in the context of normal traffic. Such methodology minimized or avoided the typical problems associated with truthfulness of self-report and reactivity to being observed.

Because of the novelty of this technology, however, a major challenge was to evaluate the Smart Car data for the most effective method of transferring electronic and videotape records to indexes of driving behavior and risk taking. Two approaches were developed and tested: (a) a time-sampling or interval approach and (b) a critical event approach. Thus, a primary purpose of the present research was to define risky driving performance from electronic records of a Smart Car and to derive a methodology for reliable data coding from videotapes of multiple ongoing driving behaviors.

METHOD

Participants and Setting

Participants were 61 licensed drivers (29 men and 32 women) from southwest Virginia, ranging in age from 18 to 82 years ($M = 42$). They were recruited with university-based flyers and advertisements in local newspapers. The flyers and newspaper ads specified that licensed drivers between the ages of 18 to 25, 35 to 45, and 65 and over were needed for a university study that involved driving, and would be paid $10.00 per hour for their participation. Drivers meeting these age requirements were grouped as younger (10 men and 13 women aged 18 to 25), middle-aged (10 men and 12 women aged 35 to 45), and older drivers (9 men and 7 women aged 65 or over).

Prior to being scheduled for an appointment, all participants were screened by verbal report for potential health problems, use of prescription medicines, and patterns of alcohol use that could potentially increase driving risk. The driving trial took approximately 1 hr to complete.

Materials

Way-finding questionnaire. To conceal the true purpose of the study, a questionnaire was administered to create the deception of a study on map-reading and direction-following skills. Specifically, prior to the driving session, all participants completed a way-finding questionnaire that asked for "yes" or "no" responses regarding one's ability to read maps, follow route directions, and ask for help when lost. This was followed by a formal map-reading exercise whereby participants drew, on a standard road map, a route from their present location in Virginia to Athens, Georgia. To enhance the deception and increase task difficulty, an inefficient route was highlighted. These data were not analyzed, but were used only to maintain the illusion of a way-finding study, as introduced in the health-screening interviews and informed consent documents. The way-finding cover story and covert video-recording procedure, as described below, received full approval by the university's Institutional Review Board.

Manipulation check. A manipulation check was presented as a "personal perception" survey. With three open-ended questions, participants were asked to describe (a) the primary objectives of the research, (b) what, if anything, they had learned from their participation, and (c) what they thought the study was about. This survey was completed immediately after the driving session.

Smart Car. All driving performance measures were collected in the instrumented vehicle whose exterior and interior were the same as a stock 1995 Oldsmobile Aurora. The car was capable of video monitoring and computer recording several driving behaviors simultaneously and unobtrusively.

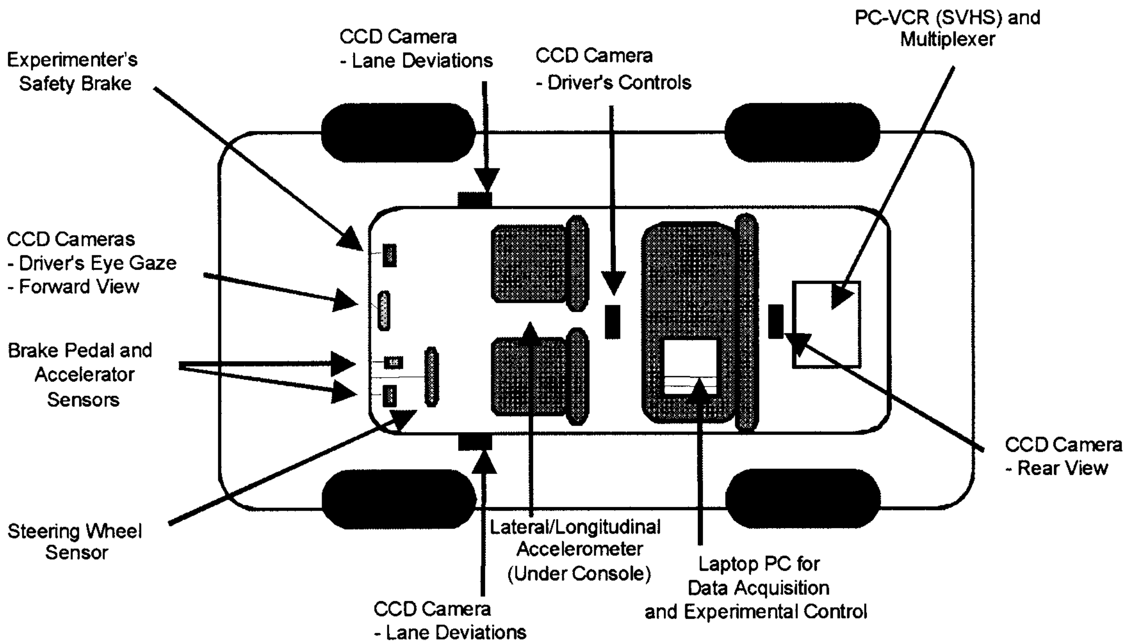

Figure 1. Diagram of the data sensor and camera locations in the Smart Car.

Figure 1 depicts a schematic diagram of the various cameras, sensors, and compilers in the Smart Car.

Four hidden cameras the size of a pinhead provided four video images. The forward-view camera provided images relevant to traffic density, road signs and markers, and headway distance from a preceding vehicle. A second camera recorded the driver's face, thereby allowing observations of head turns, eye glances, and facial expressions. A third camera recorded the location of the driver's hands. Finally, a lane-tracking camera recorded markings on the highway, including the center line.

A quad-multiplexer was used to integrate the four camera views and place a time stamp onto a single videotape record. A PC-VCR received a time stamp from the data-collection computer and displayed the time stamp continuously on the multiplexed view of the videotaped record. The PC-VCR operated in an S-VHS format so that each multiplexed camera view had 200 horizontal lines of resolution.

The in-vehicle data-collection computer provided reliable real-time measures of driving in the context of traffic. The computer had a 16-channel analog-to-digital (A/D) capability, standard QWERTY keyboard, and a 15-cm diagonal color monitor. Computer memory and processing capabilities included 128 megabytes RAM, a 1.2-gigabyte hard drive, and a 233-MHz Pentium processor.

The steering wheel, speedometer, accelerator, and brake were instrumented with sensors that transmitted data about position of the respective control devices. The steering wheel sensor provided steering position data accurate to within $\pm 1°$. The brake and accelerator sensors provided brake position within ± 0.1 inch. An accelerometer provided acceleration readings in the lateral and longitudinal planes of the vehicle. The accelerometers recorded values for vehicle acceleration and deceleration up to and including hard braking behavior as well as intense turning. These sensors provided signals read by the A/D interface at a rate of 10 times per second.

A custom interface was used to integrate the data from the experimenter control panel, driving performance sensors, event flagger, and speedometer with the in-vehicle computer. In addition, the interface provided a means to read and log the time stamp from the PC-VCR to an accuracy of ± 0.1 s. The time stamp was coded such that a precise location could be synchronized from any of the videotaped records to the computer data record for postdrive laboratory data coding and file integration.

This computer storage and control system provided the following measures: (a) driver safety-belt use; (b) number of times each turn signal was used, including left, right, and emergency flashers; (c) vehicle velocity (in miles per hour, mph) including average speed and velocity variance; and (d) vehicle following distance measured in meters.

The final video data included a continuous view of (a) the roadway environment in front of the vehicle; (b) the area directly behind the vehicle; (c) the driver's head and face, enabling a second-by-second analysis of where the driver was looking; and (d) the driver's hands, for analyzing position on the steering wheel and various in-vehicle activities such as grooming and manipulating radio knobs. Thus, the video configuration shown continuously on the video monitor allowed extensive study of ongoing driver behaviors as well as the context in which these behaviors occurred.

Procedure

Predrive. As soon as a participant arrived for a scheduled appointment, he or she was greeted by the experimenter (the senior author or a trained research assistant) and was escorted to a location with a table, chair, and all research materials. The experimenter checked each driver's license for expiration date, driving restrictions, and a match between the photograph on the license and the participant. Only one person was dismissed due to a restriction on her driver's license and for appearing intoxicated when she arrived.

Once it was determined that all license information met criteria, the participant read and signed informed consent documents that explicitly described the study as an investigation of way-finding strategies and map-reading skills. Then general procedural questions were answered, and hearing and vision tests were administered. The hearing test consisted of reading six driving-related words to the subject in a normal volume and tone. The participant was asked to repeat the words just read. Hearing was judged normal if the participant repeated each of the six words correctly.

Vision was tested with a standard Snellen eye chart. Each participant read the chart with both eyes from a marked distance of approximately 6 m. Vision was judged normal if corrected vision was 20/40 or better. Anyone whose hearing or vision did not meet criteria was thanked, given \$10.00, and dismissed. This happened on only one occasion when an older participant forgot his hearing aids.

After the routine health screenings, each participant completed the demographic and way-finding questionnaire, including the map exercise. Afterwards, the experimenter collected all pretest items and described the driving course. This presentation included spoken directions, written instructions with obvious route landmarks, and a simple map. The course was designed to account for all possible situations that could be encountered during the course of normal driving. The route included downtown, rural, and highway driving. When participants indicated familiarity with the driving course and all their questions were answered, they were escorted to the Smart Car.

Once in the vehicle, the driver's seat,

steering-wheel position, and rearview and outside mirrors were adjusted for driver comfort and safety. With the experimenter seated in the passenger side of the vehicle, participants were then familiarized with certain features of the car, including the operation of the safety belt, turn signals, windshield wipers, automatic transmission, automatic windows, defoggers and defrosters, parking brake, and the vehicle cellular phone for use in emergencies.

Participants were asked to buckle up before leaving the research site and all complied. In addition, they were told that with a driver's airbag, the safest way to hold the vehicle steering wheel was with both hands, the left at the 9:00 position and the right at the 3:00 position. All participants demonstrated the suggested hand position during its description. Any questions were answered and the driving trial was started when it was determined that the subject was buckled and reconfirmed being comfortable with the operation of the vehicle and the driving route.

Driving trial. Each participant left the research site and proceeded to the city's Main Street (a four-lane highway at this point) by way of campus roads. Once on Main Street, he or she proceeded through the business district through downtown and continued through the business district on the other side of town. Once out of town, he or she experienced approximately 2 miles of two-lane road rural driving until merging onto a four-lane divided highway on which he or she proceeded 5.2 miles. This stretch of road was hilly, with four tight roadway curves. The speed limit on this highway is generally 55 mph, but cautionary speed reductions to 35 mph occur on curved portions. When the destination, a convenience store off the four-lane highway, was reached, the participant turned around and retraced the same route. To initiate this return trip, each driver had to negotiate a difficult lefthand turn across the four-lane divided highway.

The route was 22.3 miles round-trip, took approximately 45 min to complete, and included five intersection turns, 30 controlled intersections, 2 miles of suburb driving, 6 miles of business or downtown driving, 4 miles of rural driving, and 10 miles of highway driving. Speed limits were 25, 35, 45, or 55 mph, and were marked with speed limit signs. All driving occurred in dry weather during daylight hours.

Postdrive. After approximately 40 min, the experimenter watched for a participant to return from a driving trial. Upon arrival, the experimenter greeted the driver and asked if any difficulties were experienced during the trip. Then, the participant was escorted to a posttest location furnished with a conference table, chairs, and all posttest materials. The map and driving course directions were collected, and then the participant completed the manipulation check. To maintain confidentiality, no names appeared on the questionnaire.

Results from the manipulation check revealed that 95% (58) of the 61 participants described the study as a test of direction-following and map-reading abilities. The 3 other participants indicated that they were unsure of the true purpose of the research by responding "I don't know" to each of the three questions.

Data Coding

All data-coding sessions were conducted in a quiet conference room with a large table and chairs, a television set, and a super VHS videotape recorder with a remote control. Data coding was started from the point the Smart Car crossed a stop line at the first intersection of the driving route.

Partial-interval recording. Driving behaviors were coded with a 15-s partial-interval time-sampling procedure (Kazdin, 1994).

Specifically, during each consecutive 15-s interval of the driving trial, the video record of each 45-min driving trial was analyzed for the occurrence of safe versus risky vehicle speed, speed variation, and in-vehicle (off-task) behaviors not relevant to the driving task, such as adjusting the radio, grooming, eating, using the cell phone, making hand gestures to pedestrians or other motorists, and so on.

Speed variation was measured as the occurrence or nonoccurrence of passing events during each interval. A passing event occurred when (a) a vehicle traveling in the same direction overtook the Smart Car and appeared in its entirety on the video monitor, or (b) a vehicle traveling in the same direction was overtaken by the Smart Car and went completely out of view on the video monitor.

Vehicle speed was sampled at the start of each consecutive 15-s interval by observing the speed reading that appeared on the video monitor and comparing that observation to the posted speed limit along that portion of the driving route. Speeds in excess of 5 mph over the posted speed limit were coded as risky.

The passage of each interval was indicated with a microcassette tape recorder and tape that announced the number of each new interval as calibrated to a digital stopwatch. Trained research assistants recorded their observations on a data sheet divided into numbered blocks representing each consecutive interval. This data sheet is shown in the Appendix.

Each block contained a space for descriptors of each behavioral category. Observers circled the appropriate descriptor representing the occurrence of the target behavior during that interval; otherwise it was left blank if the behavior did not occur during that 15-s time block. At the time a new interval was identified, speed was coded as either safe or risky. However, if the Smart Car was stopped due to traffic or a road signal, speed data were not recorded during that interval. Instead the descriptor "stop" was circled and this interval was eliminated from the data set.

To start an observation session, the videotape was paused at the first intersection on the route and the cassette recorder was coordinated to start the first interval as the videotape was released from the pause. The session was ended at the close of the interval during which the Smart Car crossed the same stop line that marked the start of the driving route. All data coded from this interval recording procedure were converted to "percentage safe" scores. Prior to making independent observations, all research assistants were trained to an 85% reliability criterion for each behavioral category and a 100% criterion for identifying route speed limits.

Discrete-event recording. Turn-signal use and vehicle following distance were recorded as discrete events using a safe behavior opportunity (SBO) approach (Geller, Lehman, & Kalsher, 1989). That is, an SBO for following distance occurred each time the Smart Car started to follow a new car. Each event was coded from the videotape of each participant's driving trial and matched by video frame number to the computer-recorded speed and distance measures. Following events were determined to start when (a) a car was in front of the Smart Car in the same lane, (b) the car was no more than 5 s in front of the Smart Car (the largest distance that observers could reliably perform the procedure to code the start of the event), and (c) the Smart Car was traveling at least 20 mph.

The criterion of 5 s was determined by having observers select the first available roadway landmark and counting the number of video frames that occurred from the time the back bumper of the preceding vehicle passed the landmark until the time the front bumper of the Smart Car passed the same landmark (cf. Evans, 1991; Heino, van der Molen, & Wilde, 1996). Each video frame corresponded to 0.1 s in time and was clearly visible on the television monitor.

Following events were defined as ending when (a) the Smart Car changed lanes, (b) the car being followed turned or changed lanes, (c) another vehicle entered between the vehicle that initiated the following event and the Smart Car, (d) the Smart Car was held up at a stoplight while the preceding vehicle made it through, or (e) the preceding vehicle was too far in front of the Smart Car to be reliably seen on the video monitor. To enable reliability checks, the video frame number indicating the start and end of each following event was recorded on a data-collection sheet by two trained research assistants.

Average following distances (converted to a time measure) of less than 2 s were coded as risky. For each event, the time conversion was made by assessing the ratio of following distance measured in meters and speed measured in miles per hour, and comparing it to a minimum criterion of 0.9 m, a distance that reflected 2 s of headway per mile per hour. It has been suggested by Evans (1991) and others that 2 s of headway is the minimum recommended safe following distance under normal driving conditions. The mean following distance for the entire driving trial and mean speed were also recorded.

All following events that occurred at speeds of less than 20 mph, or with no following distance recorded by the Smart Car, were eliminated from further analysis. This prevented a potential bias in the data created by the context of downtown driving, especially observations recorded when the Smart Car was routinely stopped behind other vehicles at an intersection. The percentage of following events during which the driver maintained a minimum of 2 s following distance was used as the dependent measure (i.e., percentage safe).

Turn-signal use was also coded with an SBO approach. Observers recorded the video frame numbers corresponding to the start of an intersection turn or lane change, the type of event, and its direction. The criterion used to determine the start of the SBO was the point at which the driver had committed the Smart Car to turn or change lane position (e.g., movement of the car to the center line when changing lanes). Videos could be reviewed such that only legitimate turns and lane changes were recorded. All observers were trained to a criterion of 85% reliability for determining the start of an SBO for turn-signal use.

Turn-signal SBOs were matched frame by frame to the computer record of driving performance in which left and right turn-signal use, emergency-flasher use, or no signal use were coded automatically by the Smart Car. If the correct signal was used within ± 25 frames of the number recorded during video observations (± 2.5 s of the point determined to initiate the event, as recommended by Evans, 1991), the event was coded as safe. Thus, the percentage of turns and lane changes preceded by a turn signal was used as the dependent measure. The check sheet used for coding turn-signal use and following distance is shown in the Appendix.

Interobserver agreement. Data coding was performed independently by two observers during the same session, and interobserver agreement was evaluated on an interval-by-interval basis. We calculated the number of intervals in which both observers scored the occurrence or nonoccurrence of a certain behavior (agreements), divided this total by the number of agreements plus disagreements (the number of intervals in which one observer scored the behavioral occurrence and the other did not), and multiplied by 100%. This procedure was performed separately for each of the time-sampled behaviors: speed, speed variation, and off-task behaviors.

Observations were conducted by two independent observers on 43% (26) of the 61 interval-recording sessions. Agreement was 93% for vehicle speed, 95% for speed variation, and 91% for off-task behaviors.

Turn-signal and following-distance data were coded in pairs. Interobserver agreement for turn-signal use and following distance was assessed by having videos viewed a second time by a different pair of trained observers. The data coded during the second viewing were compared frame by frame with data coded during the first viewing. An agreement was scored for an SBO for turn-signal use if (a) the two events matched within ±25 frames, (b) the direction of the event (left vs. right) was in agreement, and (c) the type of event corresponded (lane change vs. intersection turn).

Following events were scored for agreement that the same event was observed based on beginning and ending frame numbers recorded independently by each pair of observers. Agreement for the duration of following events was assessed by dividing the shorter duration recorded by the longer duration recorded and adding the fractions obtained for each following event recorded. The sum was divided by the total number of pairs of events recorded by both sets of observers and multiplied by 100%.

Independent observations were made on 33% (20) of the 60 event-recording sessions (all of the sessions for which these data were available). Agreement was 87% for turn-signal use and 85% for occurrence of a following event. Interobserver agreement for duration of following events was 87%.

RESULTS

Figure 2 provides an example of how the current data may be presented to investigate systematic relations among several driving behaviors obtained with the Smart Car. Each data point represents 1 participant's percentage safe score for each measure. The arbitrary shift in age category is indicated with the vertical dashed line. Drivers' scores are ordered from youngest to oldest within each age group along the *x* axis of each panel.

Although there were no significant gender differences for any of the five dependent measures recorded, visual inspection of the figures reveals that the variability of data points appears to decrease as a function of age category. Drawing a line arbitrarily at 75% safe reveals that among younger drivers, 57% (113) of the data points appear above this criterion. The proportion of data points above 75% increases to 71% (110) for the middle-aged drivers and 85% (80) for the older drivers. This amounts to a 25% and 50% increase in percentage safe scores from younger to middle-aged and younger to older drivers, respectively. Finally, there was a 20% increase in the number of data points above 75% safe from middle-aged to older drivers. It is noteworthy that of the five driving behaviors measured, only turn signals were used more frequently by younger drivers than by the middle-aged or older drivers.

Figure 3 highlights the relation between average speed and average following distance for the entire driving trial in a scatterplot. This figure reveals how many drivers in each demographic category fit an at-risk pattern. The diagonal line represents the 0.9-m ratio of distance in meters to speed in miles per hour that is necessary for 2 s between vehicles. In other words, those drivers falling below the line failed to maintain an average of 2 s between the Smart Car and the vehicle in front of them. A substantially greater proportion of younger drivers fall below the diagonal (61%, 23) than do middle-aged drivers (32%, 22) or older drivers (6%, 16).

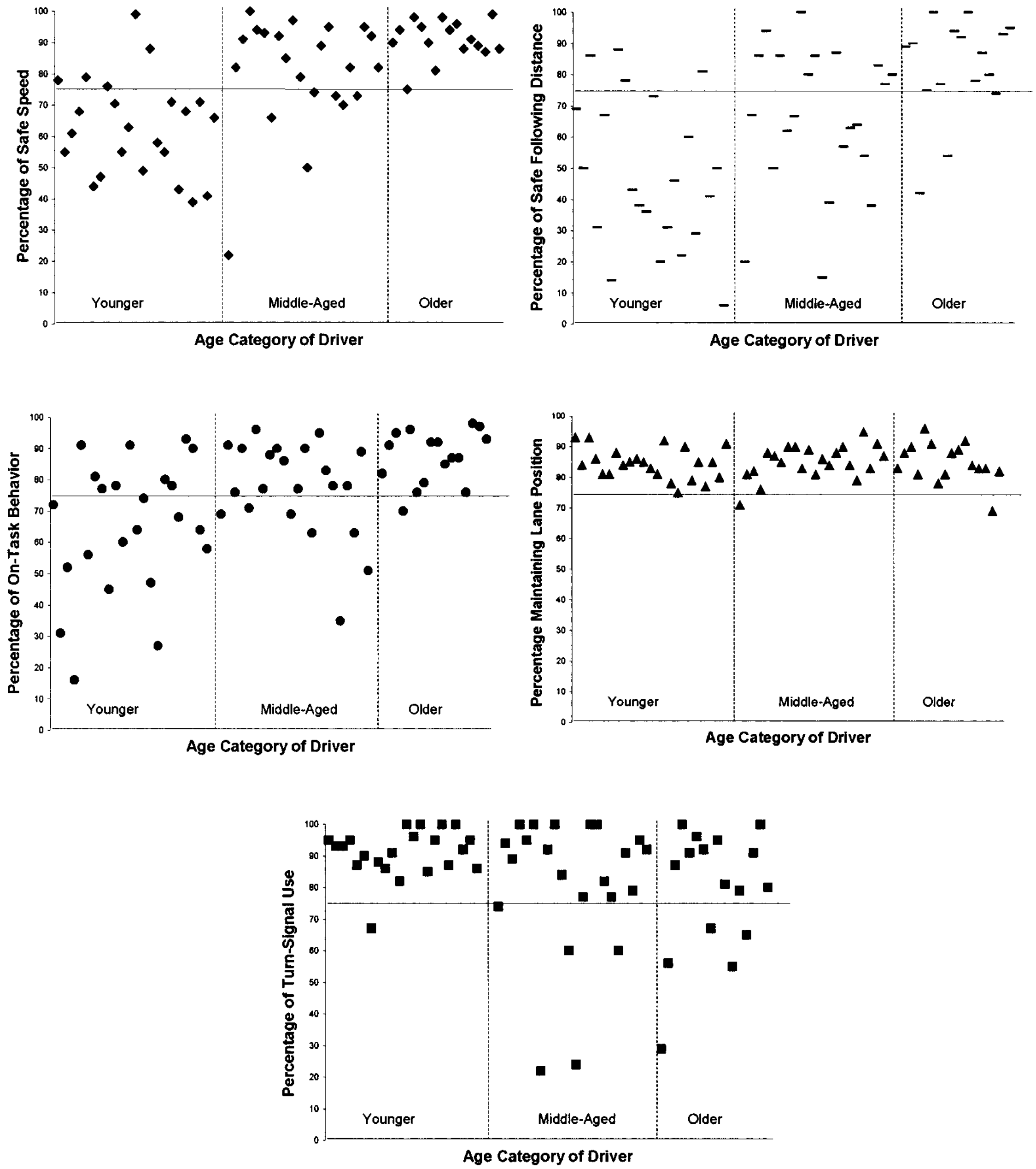

Figure 2. Between-age variation among the multiple driving measures for all participants.

DISCUSSION

The primary purpose of this research was to evaluate a method to covertly and reliably record observations of driver behavior in normal traffic. Observation methods included the use of partial-interval and discrete-event recording procedures to code data on driver speed, following distance, on-task behavior, turn-signal use, and speed variation. All data were coded from comprehensive video and computer records obtained from an instrumented vehicle without the drivers' knowledge. Thus, the present procedures allowed the study of multiple ongoing driver

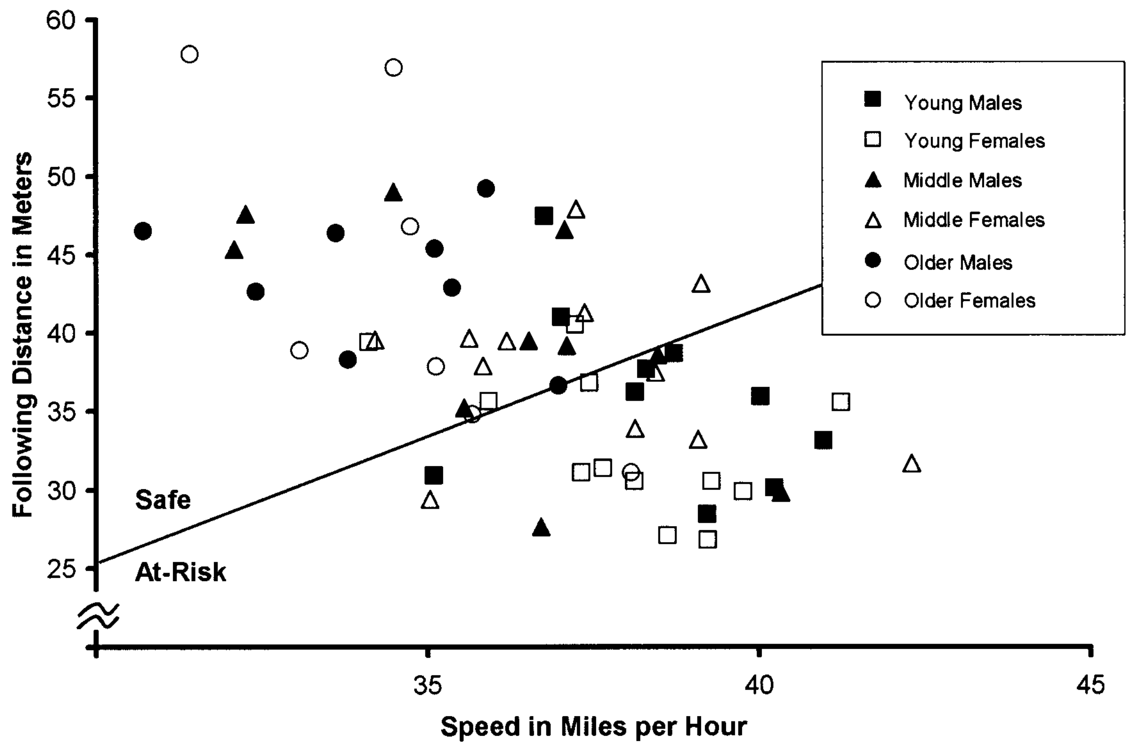

Figure 3. Scatterplot of drivers who fit the risky speed and following-distance pattern.

behaviors without reliance on self-reports or in-vehicle observers, which until now have been the research standard. As a result, the present data are relatively free from measurement error due to low truthfulness of self-report (Lajunen et al., 1997) and participant reactivity to being observed (Burns & Wilde, 1995). Although this study was not about age or gender differences in driving patterns, these data are presented to highlight how this technology may be used at an individual level to evaluate interventions designed to increase driver safety.

By performing a detailed analysis of events classified as "near misses" and safety-related errors, it is possible to obtain an indication of the relative safety of different driving conditions. The concept of measuring "close calls" in driving originated in the 1960s with the development of the traffic conflict technique or TCT (Glauz & Miglets, 1980). The technique applies the observation of crash avoidance and near-crash situations at intersections to extrapolate recommendations about hazardous intersections and appropriate intervention. A shortcoming of this technique is that it is very labor intensive. In addition, although near misses may occur more frequently than crashes, they are still too infrequent to be a sensitive measure of driving safety and crash propensity.

A methodology similar to TCT was employed in the TravTek camera car study (Dingus et al., 1995), the ADVANCE safety evaluation, the ADVANCE baseline analysis, and the crash-rate data obtained from the Illinois Department of Transportation (Mollenhauer et al., 1999). These studies analyzed near crashes in an on-road vehicle as opposed to analyzing conflicts from a stationary point. The authors argued that such an environment, particularly in the case of large-scale IVIS demonstrations, can generate data for linking measures of performance to near crashes or crashes, and can predict the impact of interventions for improving safety.

To detect the events in this series of studies, experimenters had to either ride along in the vehicles with the drivers or use obtrusive video cameras to record events inside and outside the vehicle, and later analyze videotape. They counted the number of injury crashes, noninjury crashes, near misses, and driver errors with a hazard present. The distribution of events showed a consistency between rates found in the studies at each level, providing validity for applying the concept of Heinrich's triangle (Heinrich, Petersen, & Roos, 1980) to driving. Specifically, they showed that for every injury from a vehicle crash there were 2.4 crashes without an injury, 2,838 near crashes, and 51,100 driver errors with a hazard present.

The current study developed and validated procedures for using vehicle instrumentation to detect driving risk through an analysis of ongoing driver behavior without the need for an in-vehicle observer. Because driving behavior is a sensitive measure of crash probability, a primary aim of this research was to develop a protocol for examining relations among driver demographics and several driving behaviors observed unobtrusively and without self-reports. A summary of the results obtained with the technology introduced here demonstrates the potential of this approach for analyzing multiple ongoing driving behaviors.

As expected, age was negatively related to risky driving behaviors. However, contrary to previous research, gender differences were not found. Interestingly, speeding, close vehicle following, and time spent emitting behaviors unrelated to driving correlated significantly with one another. This latter result provides evidence for response covariation, a condition presumed to be necessary for the phenomenon of response generalization (Bandura, 1969).

The power of the technology described here is demonstrated by its sensitivity to variability in driving safety. This was evidenced by the decrease in variability as participants got older. As a result of this finding, it could be argued that risky driving behaviors are "selected out" of a participant's repertoire over time, or that the participants themselves are "selected out" because of their risky driving behaviors. As such, the reduced variability among driving behaviors in older drivers may be an example of selection by consequences in a natural setting.

It has been shown consistently that men report more risky driving than women do. This was demonstrated by Wilson (1990) for safety-belt use and by Arnett (1996) for speeding, illegal vehicle passing, and driving while intoxicated. Moreover, Evans (1991) documented the overrepresentation of men in national vehicle crash statistics, and Jonah (1990) reported more pronounced age differences in driving risk for men than women. Although such findings are common, the results of the present research do not support these conclusions or the hypothesis that men in general tend to take more risks on the road than women do (Elander et al., 1993; Jessor, 1987).

It is noteworthy that the gender relations reported in previous studies of driving performance were obtained from self-report surveys. In contrast, the current data were collected without self-reports or in-vehicle observers. That is, the present behavioral data showed that men and women actually drive with relatively the same degree of risk. As suggested by Baer, Wolf, and Risley (1968), previously documented behavioral relations may be an artifact of self-report. Future research with the IVIS technology will provide more objective data to test this and answer other questions related to improving road safety through behavior analysis and intervention. For example, the present methodology could be used to establish stable baseline data among various drivers over repeated trials. These data could be compared to standard self-reported data obtained from the same participants as a measure of the validity of their verbal behavior.

Interventions can also be systematically evaluated using the present methodology. Consider that after establishing baseline among several driving behaviors, an intervention is applied systematically to certain individual behaviors in a within-subject multiple baseline across behaviors design. For example, among commercial drivers, traditional injury-prevention countermeasures (e.g., group observation and feedback) are difficult to implement because of the solitary nature of the work. However, IVIS could be applied to test various self-management techniques. Self-management is an improvement process by which individuals direct their own behavior-change efforts by manipulating behavioral antecedents and consequences (Watson & Tharp, 1997). Theoretical support for the use of self-management to improve certain behaviors is widespread (Ajzen, 1991; Bandura, 1991; Cormier & Cormier, 1985; Geller, 1998; Hayes, 1989; Latham & Locke, 1991), but applications to safety-related behaviors are rare (Geller & Clarke, 1999).

Participants could be shown a copy of their driving record and complete a survey about their current driving practices. Each participant could then evaluate his or her individual driving behaviors and select criterion behaviors for improvement. Then they would be given a critical behavior checklist to self-observe a single behavior while at least one other remains in baseline. During the research, the Smart Car method reported here would provide an objective record of change in these behaviors over time. These objective data could also be compared to the self-observed data (i.e., collected by the driver) to provide a measure of truthfulness (or reliability) of self-report. Finally, it would even be possible to investigate, in the context of driving safety, the private versus public manipulation discussed by Hayes (1989) as essential to effective self-management processes. In fact, such investigations are now more possible because the IVIS technology has been made portable, and can be retrofitted into any standard private or commercial vehicle. When removed, the vehicle is left in the same condition as it was prior to installation of the IVIS.

Use of these procedures are not without limitations. First, one must consider the ethics of obtaining videotape from participants without their explicit permission. The Institutional Review Board of the university at which the present study was conducted approved a protocol that allowed us to "hide" the video consent in our informed consent documents. Specifically, it was mentioned in the context of direction following and was worded to place a focus on video angles that recorded the roadway environment. As such, the participants were not sensitized to videotaping, although they were aware that the vehicle had "videotaping capabilities." If asked questions about videotaping during the experimental session, research assistants also emphasized video angles of the roadway environment by referring to the need to observe prominent landmarks along the driving course as a measure of the driver's progress along the route.

Second, the costs associated with running and maintaining a vehicle with this engineering technology are estimated to be approximately $80.00 per driving hour. This includes technical support to calibrate and configure the Smart Car to fit the particular needs of a research protocol. However, multiple studies with the same vehicle configuration would be less expensive. Nonetheless, in some instances multiple trials may be cost prohibitive.

Finally, mention of limitations among our measures of speeding and following distance is warranted. Specifically, our measure of percentage safe speeding coded all observations greater than 5 mph above the speed limit as risky. Thus, our measure was not sensitive to the extent drivers were exceeding the speed limit, only that they were speeding when the vehicle speed was sampled. Follow-up research should study relations with varying definitions of speeding (e.g., 5 mph vs. 10 mph above the speed limit).

Similarly, our measure of safe following distance only required subjects to maintain, on average, a minimum safe following distance of 2 s. Like our assessment of speeding, this index was not particularly sensitive to variations in the safe distance maintained. Follow-up research should define following distance with regard to degree of risk, so that longer safe or shorter risky following distances are scored on a weighted system (e.g., 2 s vs. 2.5 s behind a leading vehicle). The technology described here would permit these analyses.

The primary aim of this research was to develop and detail a process for collecting reliable observations of driving practices without the potential bias of self-reports or reactivity to an in-vehicle observer. A vehicle equipped with IVIS was used for this purpose. Measures of interobserver agreement among our observations indicated that the partial-interval and discrete-event observation techniques developed for this study can be used effectively to obtain reliable data from comprehensive video and computer records obtained from Smart Car technology. And, these data can be used to evaluate relations among several driving behaviors as they occur over time in natural traffic conditions. Perhaps the present research will serve as a catalyst for intervention research targeting multiple driving behaviors.

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APPENDIX

Data sheets used to code observations from both the partial-interval and discrete-event procedures.

Interval		1	Stop		2	Stop		3	Stop		4	Stop
Speed	S	AR		S	AR		S	AR		S	AR	
Extraneous behavior												
With Directions	YES			YES			YES			YES		
Not involving Directions	YES			YES			YES			YES		
Passing Behavior												
We Pass	L	R	Illegal	L	R	Illegal	L	R	Illegal	L	R	Illegal
They Pass	L	R	Illegal	L	R	Illegal	L	R	Illegal	L	R	Illegal

Interval		5	Stop		6	Stop		7	Stop		8	Stop
Speed	S	AR		S	AR		S	AR		S	AR	
Extraneous behavior												
With Directions	YES			YES			YES			YES		
Not involving Directions	YES			YES			YES			YES		
Passing Behavior												
We Pass	L	R	Illegal	L	R	Illegal	L	R	Illegal	L	R	Illegal
They Pass	L	R	Illegal	L	R	Illegal	L	R	Illegal	L	R	Illegal

Interval		9	Stop		10	Stop		11	Stop		12	Stop
Speed	S	AR		S	AR		S	AR		S	AR	
Extraneous behavior												
With Directions	YES			YES			YES			YES		
Not involving Directions	YES			YES			YES			YES		
Passing Behavior												
We Pass	L	R	Illegal	L	R	Illegal	L	R	Illegal	L	R	Illegal
They Pass	L	R	Illegal	L	R	Illegal	L	R	Illegal	L	R	Illegal

	Turn-Signal Use				Following Distance			
SBO	Frame #	Beh	Safe	At-Risk	Frame # Begin	Frame # End	Safe	At-Risk
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

STUDY QUESTIONS

1. Briefly describe the recording instruments that made up the Smart Car and indicate what was monitored by each of these instruments.

2. What was the purpose of the predrive condition?

3. Summarize the characteristics of the driving route.

4. What measures were coded using the partial-interval recording system? Which of these measures actually constituted a time-sampling method?

5. Indicate which events were documented using the discrete-event recording system and briefly describe how each of these events was defined.

6. Summarize the results across behavioral categories when organized according to age.

7. What types of variables may result in changes in these indexes across time?

8. The authors suggest several ways that the Smart Car technology could be used to measure driving ability. How might this technology be extended to implement automated interventions for unsafe driving?

Questions prepared by Rachel Thompson and John Adelinis, The University of Florida